EFFECT OF VOLUME FRACTION ON THE FLEXURAL STRENGTH AND MODULUS OF WOVEN COMPOSITE

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

The project entitled The Effect of Fiber Volume Fraction on The Flexural Properties of Woven Composite generally explained the effect of increasing fiber volume fraction on the behaviour of flexural properties of woven composite. This behaviour can be interpreted into flexural properties versus fiber volume fraction curve which will show how these properties evolve whether increased or decreased when the fiber volume fraction is increased. The woven composite is fabricated with woven glass fiber and polyester resin through hand lay up method with the fiber volume fraction ranging from 0.17 to 0.33. Specimens are made out of the composite with six samples for each fiber volume fraction to be tested through the flexural test based on JIS K 7055, Testing method for flexural properties of glass fiber reinforced plastics. Japanese Standards Association. The specimens were tested under 50kN of flexural load and then a load-displacement curve was obtained to find the flexural strength and flexural modulus of the composite using two specific formulas. From these data, two graphs of flexural strength and flexural modulus versus fiber volume fraction were plotted so that the behaviour of these two properties can be observed. From this test, the graphs produced was almost consistent with the previous studies which is both of the flexural properties were increased linearly due to the increasing of fiber volume fraction until it reached a certain stage where the volume of the resin is no longer enough to cover the entire composite. Thus, the load cannot be distributed effectively by the resin which caused both properties to decreased when it reach $V_f = 0.33$.

ABSTRAK

Projek ini yang bertajuk "Effect of Volume Fraction on Flexural Strength and Modulus of Woven Composite" secara amnya menerangkan kesan peningkatan pecahan isipadu ke atas kelakuan sifat lenturan komposit teranyam. Kelakuan ini boleh di terjemahkan kepada lengkungan sifat lenturan melawan pecahan isipadu gentian yang mana akan menunjukkan bagaimana sifat-sifat ini berkembang sama ada meningkat atau berkurang apabila pecahan isipadu gentian meningkat. Komposit ternyam ini diperbuat dengan gentian kaca teranyam dan resin polyester melalui kaedah "Hand Layup" dengan pecahan isipadu gentian terlingkung di antara 0.17 dengan 0.33. Spesimen-spesimen diterbitkan dari komposit teranyam dengan enam sampel bagi setiap pecahan isipadu gentian untuk diuji melalui ujian lenturan berpandukan "JIS K 7055, Testing method for flexural properties of glass fiber reinforced plastics. Japanese Standards Association". Spesimen-spesimen ini telah diuji dibawah 50kN bebanan lenturan dan kemudian memperolehi lengkungan bebanan-perubahan untuk mencari kekuatan lenturan dan modulus lenturan menggunakan dua formula khusus. Daripada data-data yang diperolehi, dua graf terbentuk iaitu kekuatan lenturan dan modulus lenturan melawan pecahan isipadu gentian supaya perlakuan kedua-dua sifat ini boleh diperhatikan Daripada ujian ini, graf yang diperolehi hampir menyamai graf dari kajian-kajian yang lepas dimana kedua-dua sifat lenturan meningkat dengan peningkatan pecahan isipadu gentian sehingga ia mencapai satu peringkat dimana isipadu resin tidak lagi mencukupi untuk menutupi kesemua bahagian komposit teranyam. Oleh sebab itu, bebanan tidak boleh disebarkan secara berkesan oleh resin yang mana telah menyebabkan kedua-dua sifat lenturan berkurang apabila pecahan isipadu mencapai 0.33.

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LIST OF SYMBOLS

V_f	Fiber volume fraction
E_1	Longitudinal Modulus
δ	Deflection
P	Force
A	Cross section area
L	Length
E_2	Transverse Modulus
ν_{12}	Poisson's Ratio
G_{12}	Shear strength
σ_f	Flexural Strength

LIST OF ABBREVIATIONS

FRP	Fiber reinforced plastic
GFRP	Glass fiber reinforced plastic
GRP	Glass Reinforced Plastic

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

A 'composite' is a heterogeneous combination of two or more materials (reinforcing agents & matrix), differing in form or composition on a macroscale. The combination results in a material that maximizes specific performance properties. The constituents do not dissolve or merge completely and therefore normally exhibit an interface between one another. In this form, both reinforcing agents and matrix retain their physical and chemical identities, yet they produce a combination of properties that cannot be achieved with either of the constituents acting alone.

Composites are commonly classified based on the type of matrix used: polymer, metallic and ceramic. In fiber – reinforced composites, fibers are the principal load carrying members, while the surrounding matrix keeps them in the desired location and orientation. Matrix also acts as a load transfer medium between the fibers, and protects them from environmental damages due to elevated temperatures, humidity and corrosion. The principal fibers in commercial use are various types of glass, carbon and Kevlar. All these fibers can be incorporated into a matrix either in continuous or discontinuous form.

Composite materials have unique, useful and superior performance that can be predicted from the properties, amounts and arrangements of constituents using principles of mechanics. Compared to conventional engineering materials, composites can be designed to produce exceptional strength and stiffness with minimum weight. They are 30-45% lighter than aluminium structures designed for the same functional requirements. They also perform an excellent corrosion resistance and enjoy lower life cycle cost compared to metals. They are also having improved torsional stiffness, impact resistance properties and appearance with smooth surfaces. The composite are flexible in design and are more versatile than metals and can be tailored to meet performance needs and complex design requirements)

The purpose of this project is to fabricate the composite of glass fiber reinforced polyester with the increase of fiber volume fraction for every composite and to prepare the specimen to conduct the flexural test.

In order to start this project, the objectives and scopes of this project will be stated as a guide during the whole process. Then, the problem involves have to be determined to explain why this experiment must be conducted.

1.2 OBJECTIVES OF THE RESEARCH

a) To fabricate the woven composite using hand layup method
b) To investigate the effect of volume fraction on flexural properties and modulus of woven composite

1.3 SCOPES OF THE RESEARCH

The purpose of this project is to observe the effect of different fiber volume fraction on the flexural strength and modulus of woven glass fiber reinforced polyester composite.

i) Fabrication of woven composite plate
ii) Specimens preparation
iii) Flexural test
iv) Data analysis

1.4 PROBLEM STATEMENT

i) The usage of woven composites has increased over the recent years due to it unique and superior performance that can be predicted from mechanical properties.
ii) Studies had discovered that increase of reinforced element addition produced better mechanical properties such as flexural strength which is the ability of a material to bend before it breaks
iii) Investigate the behavior of flexural strength and modulus upon the increasing of fiber content in the composite

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The usage of woven composite has increased over the years due to their lower production costs, lightweight, higher fraction toughness and better control over the thermo-mechanical properties (Bystrom, Jekabsons, Varna, 2000). For instance, these composite materials are being considered for commercial aircraft fuselage structures. Hingeless and bearingless helicopter rotor hubs that are designed using laminated composite materials experience centrifugal loads as well as bending in the flapping flexure region (Murri, O'Brien, Rousseau, 1997).

2.2 COMPOSITE

Composite is a material created from fibers (or reinforcement) embedded in an appropriate matrix material so that the specific performance properties can be enhanced (Nonwovens in Advance Fiber Composites, 1989). It contains at least two constituents that can be physically or visibly differentiated. The constituents do not completely merge together, creating new identity but their properties are remaining the same as they were joined.

Fiber-reinforced composites have very high strength to weight and stiffness to weight ratios which make them lightweight. They also have electrical insulation properties which make them suitable materials in making electrical appliances and tools. That is why most aerospace and high performance sporting goods are made by them. Experienced have proved that the use of composites allows one to obtained weight reduction varying from 10% to 50%, with equal performance, together with a cost reduction of 10% to 20%, compared making the same piece with conventional metallic materials (Gray, Hoa, 2007). Other significant benefits of composites are excellent durability and corrosion resistance, good fatigue behavior and dimensional stability. Commonly used reinforcing fiber materials include metals, ceramics, glasses and carbon. The fiber can be in continuous or discontinuous forms.

There are a lot of traditional ways to make the fiber reinforced composites, such as injection molding, and wetlay process. The idea of wetlay process was proposed by inventor Gregory P. Weeks in his patent (Weeks, 1989). It provides a way to make composite of highly homogeneous distribution of the glass fiber and the thermoplastic resin matrix.

2.2.1 Reinforcement

During the manufacturing process of the composite material, the bonding between fibers reinforcement material and matrix is created which give the fundamental influence on the mechanical properties of the composite material.

Fibers consist of thousands of filaments which the diameter ranges between 5 and 15 micrometers, allowing them to be producible using textile machines. These fibers are manufactured in the form of short fibers with lengths of a few centimeters of fractions of millimeters are felts, mats and short fibers used in injection molding. The other form is long fibers which are cut during time of fabrication of the composite material, are used as is or woven.

In forming fiber reinforcement, the assembly of fibers to make fiber forms for the fabrication of composite material can take the form of unidimensional (unidirectional tows, yarns or tapes), bidimensional (woven or nonwoven fabrics) and tridimensional (fabrics with fiber oriented along many directions)

Fiber reinforcement materials are added to the resin system to provide strength to the finished part. The selection of reinforcement material is based on the properties desired in the finished product which do not react with the resin but are complete part of the composite.

There are three basic types of fiber reinforcement materials that are commonly used which are aramid fibers, carbon/graphite fibers and glass fibers. Four main factors govern the reinforcing fiber's contribution in the composite are:

a) The basic mechanical properties of the fiber
b) The orientation of the fibers in the composite
c) The amount of fiber in the composite (Fiber Volume Fraction)
d) The surface interaction of fiber and resin

Numerous studies have demonstrated the relationship between the quantity of fibers in the polymer matrix and the flexural and impact strength of fiber reinforced construction. (Valittu, 1997, Narva, 1999).

It has been described by increasing the fiber content the flexural strength increases linearly according to the law of mixtures (Behr, Rosentritt, Lang, Handel, 2000). It is preferable to define the fiber quantity in the polymer matrix in volume percentage rather than weight percentage. (Valittu, 1997).

2.2.2 Matrix

The matrix materials include polymeric matrix (thermoplastic resins and thermoset resins), mineral matrix (silicon carbide, carbon which can be used at high temperatures) and metallic matrix (aluminium alloys, titanium alloys, oriented eutectics)

Resin can be thermosetting or thermoplastic resins. Thermoset resin requires addition of curing agent or hardener and impregnation onto a reinforcing material, followed by a curing step to produce a cured or finishing part. Thermoset resins cure into an irreversible state that caused by a cross-linking in the molecule structure. Examples of thermoset resins for composite are unsaturated polyester, vinyl ester, epoxy, urethane and phenolic.

Thermoplastic resin has a linear molecule structure that will soften repeatedly when heated to its melt temperature and harden when cooled. Examples of thermoplastic resins for composite are polypropylene, polyethylene, polystyrene, nylon, polycarbonate and thermoplastic polyester.

Composite are classified according to their matrix phase which are:

a) Polymer Matrix Composites (PMC's)
b) Ceramic Matrix Composites (CMC's)
c) Metal Matrix Composites (MMC's)

Materials of these categories are often called "advanced" of they combined the properties of high strength and high stiffness, low weight, corrosion resistance, and electrical properties in some special cases. The combination of properties make advanced composite very suitable for aircraft and aerospace structural parts (Vaughan. 1998).

A research conducted by Buereau and Denant (Bereau and Denault, 2000) showed that matrix type affects the behavior of glass fiber/polypropylene composites. They found that a composite with a thermoplastic matrix has 2-stage fatigue damage and that with a thermoset matrix has 3-stage fatigue damage. The fatigue behavior is characterized by the spherulitic regions formed within the composite.

2.2.3 Material Orthotropy

Properties of composite layer strongly depend on the form of the reinforcement in the laminate. Those properties, which are the strength, stiffness, thermal and moisture conductivity, wear and environmental resistance, are actually depend on the directional fibers in the fiber-reinforced laminate. Materials whose properties are independent of direction are called isotropic materials while materials with different properties in different direction are called anisotropic. Orthotropic is a materials when two mutually perpendicular planes of symmetry existed in material properties. It is a special case of anisotropy. Some materials that are included as orthotropic are fibrous composites with either short fibers or continuous fibers. In such composite, its properties are defined in the plane of the layer in two directions- the direction along the fibers and the direction perpendicular to the fiber orientation.

2.2.4 Unidirectional Composite Material Coordinates

Unidirectional fibers are the simplest arrangement of fibers to analyse. The basic element of a unidirectional composite is a thin sheet (*ply*). They provide maximum properties in the fiber direction, but minimum properties in the transverse direction. By convention, the principal axes of the ply are labeled '1, 2, 3'. This is used to denote the fact that ply may be aligned differently from the Cartesian axes x, y, z. Material axes are defined as follows:

- Longitudinal direction (1) – parallel to fibers
- Transverse direction (2) – perpendicular to fibers in plane
- Normal direction (3) – out of plane

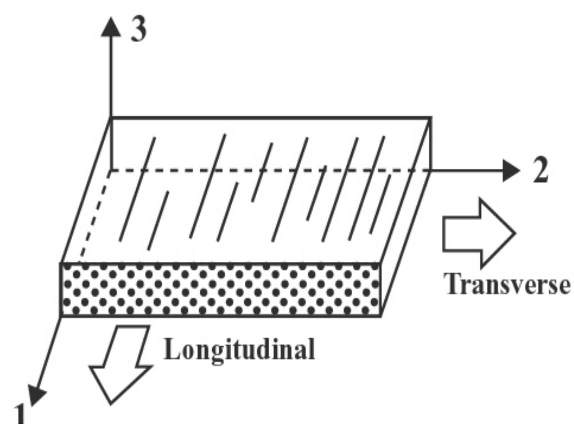

Figure 2.1: The longitudinal and transverse direction in unidirectional composite

2.2.5 Rule of Mixture

Rules of Mixtures are mathematical expressions which give some property of the composite in terms of the properties, quantity and arrangement of its constituents. It is one of the ways to estimate composite material by summarizing the properties of the individual constituents based on their contribution to the overall material volume. It is also employs the volume fraction of the constituents to estimate the properties of the composite.

In the case of a continuous fiber-reinforced composite layer, a fiber volume fraction V_f and a matrix volume fraction V_m, must satisfy

$$V_f + V_m = 1 \tag{2.1}$$

Based on the rule of mixtures, a property p is estimated from the constituent properties, p_f and p_m, as

$$p = p_f V_f + p_m V_m \tag{2.2}$$

$$= p_f V_f + p_m (1 - V_f) \tag{2.2.1}$$

The longitudinal stiffness property, E_1, of the composite maybe calculated from the Young's moduli of the constituents E_f and E_m, using this rule of mixtures as

$$E_1 = E_f V_f + E_m V_m \tag{2.3}$$

The total end-deformation δ of the composite is identical in the fiber and the matrix,

$$\delta_f = \delta_m = \delta \tag{2.4}$$